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# Session 2A: Groundwater

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# HOW CLOSE DO WE NEED TO SAMPLE FOR APPROPRIATE SOLUTE TRANSPORT CHARACTERIZATION THROUGH THE VADOSE ZONE?

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Soil hydraulic properties and solute transport characteristics in the soil profile strongly affect the transport velocity of chemicals through the vadose zone and to the ground water. Especially the soluble components of surface-applied mineral and organic fertilizers as well as pesticides can quickly be transported downward in the soil profile and leach to the ground water. Managing our soils with the focus on ground and surface water quality implies a thorough analysis of transport paths and transport behavior through soils while efficiently taking advantage of retention and transformation processes in soils. The objective of this study is to quantify solute transport coefficients for a conservative tracer in an agriculturally managed field soil based on time series of solute concentration and the upper boundary condition.

Quantification of transport behavior in field soils is a complex task especially due to the fact that residential concentration of solutes is spatially extremely variable, even over short spatial distances. For this reason, in many cases, only a field-average transport behavior is approximated. This average result is, however, unsatisfactory inasmuch as the local scale transport behavior is not addressed. The underlying long-term task is to quantify the impact of management, coincidence of timing and rainfall intensity on solute transport through the vadose zone.

In order to determine solute flux rates based on residential concentration at a given location, a time series of solute concentration needs to be derived for that location. For this purpose, the spatial autocovariance behavior is quantified, in other words, the spatial distance represented by an individual soil sample has to be derived. The sample volume, i.e., the size of the auger strongly affects this distance. The pilot study presented here is focused on a transect experiment. A 16-m-transect was divided into zones of varying initial soil water content by pre-wetting a distance of approximately 11 m. A bromide tracer was applied to the soil surface through sprinkler irrigation, followed by two 20-mm-rainfall events. At the 0-10 cm depth, solute concentration - presented here as total anions – proceeded randomly in space due to the large amount of soil organic matter and debris at the soil surface. At the following soil depths down to 50 cm, anion concentrations were spatially correlated over 4 to 5 lag distances, corresponding to a distance of 1 to 1.25 m. The sampling scheme derived in this pilot study will be used in the subsequent experiment where rainfall intensity and timing of pesticide application prior to rainfall is investigated.

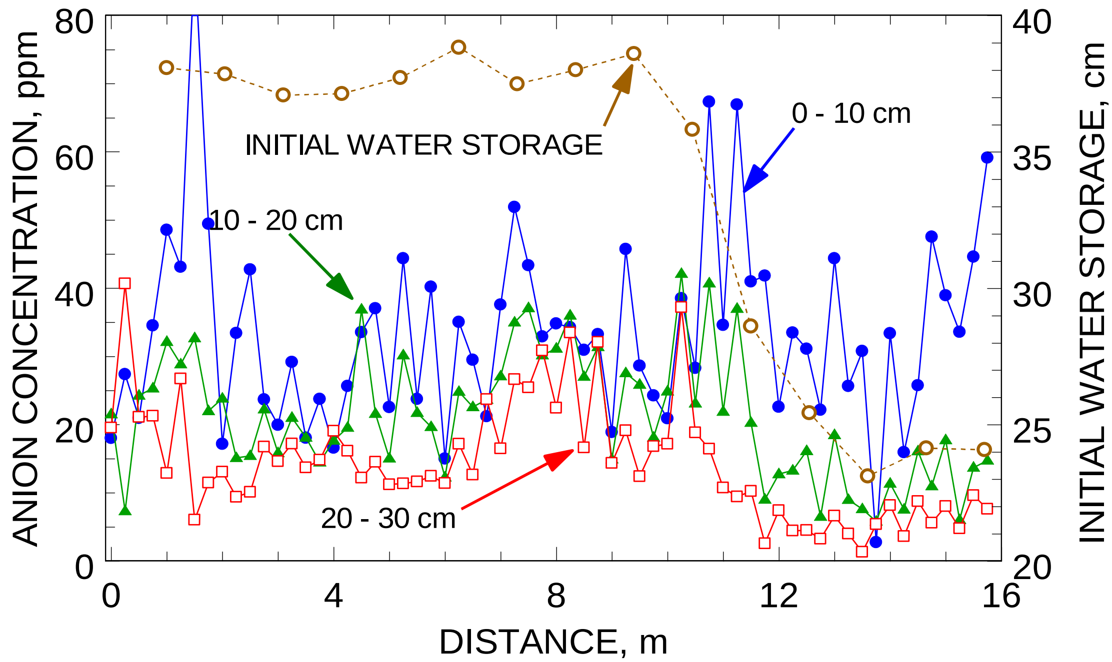


Figure 1. Initial profile soil water storage and anion concentration after 45 mm of rainfall along the transect.

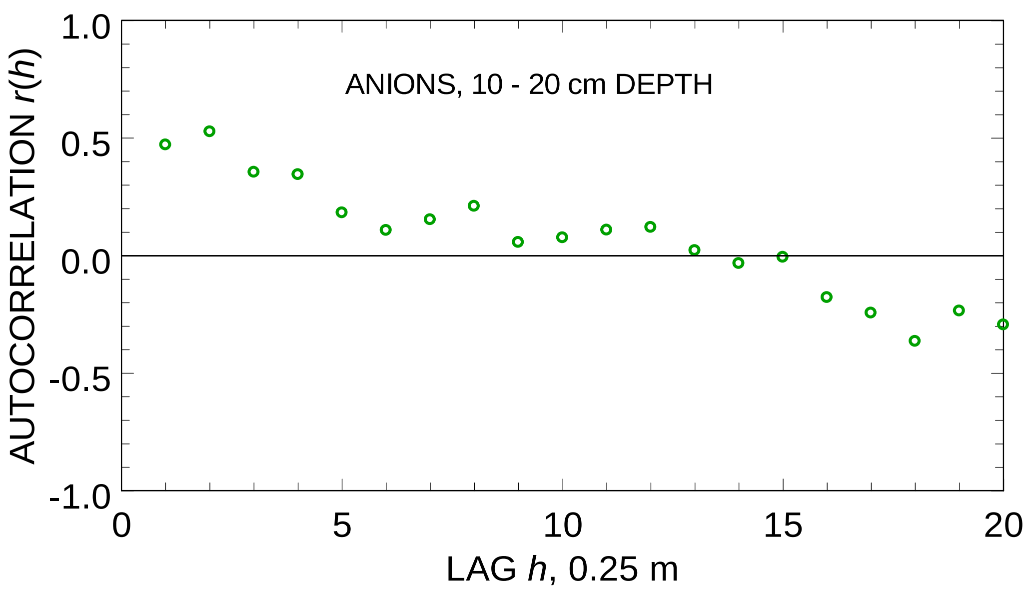


Figure 2. Spatial autocorrelation of anion concentration versus lag distance at the 10-20 cm soil depth, manifesting a covariance structure of 1 m.

EFFICIENTLY LOCATING AND REPAIRING DAMAGED SEWER LINES IN A KARST TERRANE

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In early September 2007, raw sewage was reported to be contaminating a reach of Town Branch Creek in Lexington, Kentucky. The source of the pollution was found to be a spring on the south side of the creek located in a Mixed-Use Industrial area of town. Spring flow from the limestone bedrock was estimated at 0.5 cubic feet per second (cfs). Initial observations of the spring discharge showed high levels of fecal contamination and a strong sulfur smell. Low dissolved-oxygen values and stressed algal growth were observed downstream of the contaminated spring.

A "shotgun approach" of dye-testing, line cleaning, and televising were all started on nearby sewer trunk lines in an attempt to locate the leaking section of pipe. Geologists from the Kentucky Geological Survey were consulted for information on groundwater flow associated with the contaminated spring. After studying confirmed dye-trace data for the spring, our search was expanded to dye test the trunk lines that collect sewage from over 3000 acres of the Urban Service Area of Lexington. All dye traces were then coordinated by one section of the Division of Water and Air Quality (DWAQ) with a modified approach, similar to a karst investigation. DWAQ, with the assistance of the KY Division of Water, conducted coordinated tracing to identify one trunk line draining nearly 1300 acres as leaking into the spring recharge area. Systematic dye testing along the trunk line narrowed the leaking section down to a 2000 foot reach of Vitrified Clay Pipe (VCP), over 4000 feet south of the spring.

The contaminated spring rises in Town Branch were contained in Corps of Engineers approved dams and all discharges were pumped into a sanitary trunk line for treatment. The damaged 18" VCP trunk line was then cleaned and televised to locate the leaking sections of pipe. Point-repairs were made to replace the worst sections of pipe and smaller leaks were repaired using Cure-In-Place-Pipe (CIPP) sleeve linings.

Stream and spring conditions were continually monitored and tested for fecal coliform, conductivity, pH, ammonia content and dissolved oxygen, with all results being sent to the Kentucky Division of Water.  Subsequent dye-tracing has confirmed that this section of sewer line has been repaired and is no longer contaminating the spring.

HYDROGEOLOGIC INVESTIGATIONS OF PAVEMENT SUBSIDENCE IN THE CUMBERLAND GAP TUNNEL

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On October 18, 1996, the portion U.S. Highway 25E from Middlesboro, Kentucky, to Harrogate, Tennessee, was relocated into a newly constructed tunnel beneath Cumberland Mountain to both improve transportation efficiency and safety, and to help restore Cumberland Gap to its appearance when Daniel Boone brought the first settlers to Kentucky in the mid 1770's. The tunnel is approximately 4,150 ft. long and consists of two bores, one southbound and the other northbound, each having two lanes for traffic. Approximately 26,000 vehicles pass through the two bores each day. The stratigraphic section pierced by the tunnel consists of primarily carbonate rocks of upper Silurian age and Mississippian age, and clastic strata of lower Pennsylvanian age. Cumberland Mountain is on the southeastern margin on the structural wedge of the Pine Mountain thrust sheet. The strata are tilted approximately 40 degrees to the northwest, and there are no major faults. The tunnel transects the strata at almost 90 degrees.

In June, 2002, it was observed during routine maintenance that short, discrete sections of the highway pavement were beginning to subside in both the southbound and northbound bores in the part of the tunnel bored through the Pennsylvanian age strata; no pavement subsidence has been noted in the southern third of the tunnel which is bored in carbonate rock. Ground penetrating radar surveys conducted by the Kentucky Transportation Center, University of Kentucky, indicated that the aggregate roadbase, commonly referred to as Number 57 limestone aggregate, had subsided away from the concrete pavement in at least 6, nearly juxtaposed locations in each bore. The proximity of the subsidence in the two parallel bores indicates involvement of discrete geologic strata or structure. Limited pavement core holes and lithologic core borings indicate subsidence in the aggregate roadbase of at least 2 feet from the pavement. Hydrogeotechnical documentation of conditions encountered in the initial pilot tunnel and during the construction of the two highway bores indicates the local presence of zones of high groundwater discharge, occurrence of mudstone strata, major joints and minor faults, or combinations thereof in the subsidence zones.

An initial hypothesis was that convergence of groundwater flow and resulting increased velocity in the subsidence zones, into and through the drainage field in the aggregate roadbase, might be physically eroding the aggregate or creating upwelling conditions into which aggregate was sinking. Either or both of these processes would undermine support for and lead to subsequent subsidence of the overlying pavement. However, observations at access portals for the groundwater drainage system did not reveal the movement of any large amounts of sediment, and the alkaline pH and electrical conductivity measurements less than 250 uS of groundwater in the drainage system were not indicative of groundwater dissolution of rock material at a rate sufficient to cause the observed subsidence.

Intensified hydrogeologic and hydrogeochemical studies have been pursued in the southbound bore in the past three years. Dye tracing and particle tracing, using both *Lycopodium* spores and colored glass spheres (0.5 mm diameter), were employed to help define the groundwater flow within the roadbed aggregate. Dye recovery indicated that all the groundwater entering the tunnel aggregate is being transported through the designed drainage system; there is no extraneous groundwater flow out of the tunnel that could carry rock material from the tunnel unobserved. Dye tracing also indicated that groundwater velocity in the aggregate was approximately 0.02 ft/sec (0.49 cm/sec). The velocity needed to suspend and transport the 0.5 mm spheres is 0.12 to 0.22 ft/sec which explained why no glass sphere were recovered in plankton sampling nets installed in the drainage system. Likewise, no *Lycopodium* spores were recovered in the nets, for unknown reasons.

In the summer of 2006, five core borings were completed in the southbound bore in several subsidence zones to look at the stratigraphy of the underlying bedrock. A downhole video camera documented geologic conditions in the bore hole, and groundwater head was measured by straddled packers in discrete 7.12 ft intervals in two of the core borings. Cores and video logs show voids that range from a few inches to 2.5 ft. in bedrock, and the presence of highly weathered zones without noticeable distinction among bedrock lithologies which consist primarily of shales, siltstone, sandstone, and orthoquartzite. In a total of 210 ft. of core, no significant calcite-rich strata were observed. Perhaps the voids and highly weathered zones represent zones where calcite-rich strata have been dissolved since construction of the tunnel. Video logs indicated that in several void areas, groundwater velocity was great enough to move the camera, and carry rock particles horizontally across a void, and upward in the bore hole. Straddle-packer measurements indicated vertically upward groundwater movement in the bedrock.

In the spring of 2007, several monitoring wells were driven through the roadbase limestone aggregate to the top of bedrock. Water quality analyses and geochemical modeling indicated that the groundwater in these wells was aggressive with respect to calcite. In the summer of 2007, a 115 foot-long section of the highway pavement and limestone roadbase aggregate was excavated in a subsidence zone. Several high volume springs were observed on the bedrock floor, one having a pH of 6.0. The roadbase aggregate exhibited rounded and etched surfaces, and a particle size analysis indicated that there was a reduced percentage of fines in the aggregate and that the coarse-fraction particles were reduced in size by approximately 30 percent when compared to standards for Number 57 aggregate. These observations indicate limestone dissolution by groundwater. In September, 2007, 25 monitoring wells were driven through the aggregate to refusal at the bedrock surface in both the southbound and northbound bores to monitor groundwater levels and water quality up gradient, within, and down gradient of the six prominent pavement subsidence zones. Water-quality modeling of water samples collected in October and November indicate that although pH is predominantly above 7.0, most groundwater is still aggressive towards calcite dissolution ($pH < 8.4$) and, hence, limestone aggregate dissolution. Preliminary mass flux estimates indicate that the volume of subgrade loss is approximately 0.6 $ft^3$/day/bore.